Tenaris TEM PALOY AA-1
Tenaris is the leading global manufacturer and supplier of tubular products and services used in the drilling, completion and production of oil and gas and a major supplier of tubular products and services used in process and power plants and in specialised industrial and automotive applications.

Through our integrated global network of manufacturing, R&D and service facilities, we are working with our customers to meet their needs for the timely supply of high performance products in increasingly complex operating environments.
Introduction

Tenaris’s TEMPALOY AA-1 is a 18Cr-10Ni-3Cu-Ti-Nb-B austenitic stainless steel developed for boiler construction, in particular for the fabrication of superheaters and reheaters. Its specific chemical composition, developed and tailored by Tenaris NKKTubes, produces a steel with extremely high creep and corrosion resistance. This is a key requirement for advanced materials used for supercritical and ultra-supercritical boilers. Tenaris’s TEMPALOY AA-1 is suitable for applications with steam temperatures up to 650°C (1202°F). TEMPALOY AA-1 tubes are produced for Tenaris by Sanyo Special Steel Co. Ltd. in Japan.

Key features

- 18Cr-10Ni austenitic stainless steel with addition of 3% Cu, Nb, Ti and B to maximise creep strength
- Excellent and long-term stable creep properties up to 750 °C (1382 °F)
- High oxidation and corrosion resistance at elevated temperatures
- Possibility to perform internal shot-blasting to further increase steam oxidation resistance
- M aximum design temperature is 750 °C (1382 °F) according to ASTM E Code Case 2512
- Balanced chemical composition to avoid embrittlement after long term high temperature exposure.

Applicable international codes and standards

- ASTM A213 S30434
- ASME Code Case 2512
- METI SUS321J2HTB
- VdTÜV-Werkstoffblatt 564/2
- EN 10216-5 application pending

Chemical composition, microstructure and mechanical properties

The chemical composition, as specified by ASTM A213 and ASME E Code Case 2512, is reported in Table 1. Table 2 reports the minimum mechanical properties required by ASTM and ASME E codes.

The level of Cr and Ni confers a stable austenitic structure free from δ-ferrite, as shown in Fig. 1. The addition of Nb and Ti promotes the formation of fine M X type precipitates, besides Cr-rich M 23C 6.

Through the addition of Cu, a coherent Cu-rich phase precipitates, increasing significantly the creep resistance of the steel.

The studies performed by the R & D centre of TENARIS NKKTubes showed that an addition of 3% of Cu guarantees a significant increase of creep strength of the material (Fig. 2). The microstructure obtained is very stable, as confirmed by the long term creep and ageing tests performed on TEMPALOY AA-1 (Fig. 5).

Not only the creep performances of TEMPALOY AA-1 are outstanding, but this steel maintains also a high toughness after long exposure at service temperature. After ageing tests performed between 650 °C and 750 °C up to 10000h, TEMPALOY AA-1 shows impact values always above 100J/cm².

The heat treatment consists of a solution annealing at a temperature above 1160 °C (2120 °F) followed by rapid cooling in water or in other medium.

The heat treatment temperature range has been optimised to maximise the long term creep properties by promoting a fine and diffuse precipitation of M X carbides during exposure at service temperature.
Creep properties and allowable stresses

Temaloy AA-1 has been extensively characterised regarding creep properties. Creep tests have been performed at 600, 650, 700, 750 and 800°C at different stresses with test durations also longer than 10⁵h and with more than 1.5 million broken creep test hours. The ECCC (European Creep Collaborative Committee) guidelines have been followed for the assessment and PATs (Post-Assessment-Tests) have been successfully passed, confirming the quality and the consistency of the results. The assessed values are reported in Table 3.

The allowable stresses for the design according ASME rules are given in ASME code case 2512. The values are reported in Table 4.

**Table 3 – Assessed average creep rupture strength. The lower scatter band is usually defined as the 80% of the average creep strength**

* Extrapolation at 200000 h not covered by PATs

**Table 4 – Allowable stresses from ASME code case 2512 (table 3M)**

GENERAL NOTE: The revised criterion of 3.5 on tensile strength was used in establishing these values.

NOTE: (*) Due to the relatively low yield strength of this material, these high stress values were established at temperatures where the short-time tensile properties govern to permit the use of these alloys where slightly greater deformation is acceptable. These higher stress values exceed 66 2/3%, but do not exceed 90% of the yield strength at temperature. Use of these stresses may result in dimensional changes due to permanent strain. These stress values are not recommended for the flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.

(from ASME code Case 2512)
Steam oxidation and corrosion resistance

High temperature corrosion and steam oxidation resistance are key parameters for the selection of boiler materials. Specific tests were performed on TEMPALOY AA-1 to evaluate the corrosion resistance in simulated coal ash and heavy oil combustion atmospheres.

The results achieved show good corrosion resistance thanks to its high Cr content. Steam oxidation properties have also been evaluated at different temperatures.

The results of laboratory steam oxidation tests performed at different temperatures for 1000h are reported in Fig. 3 compared with the benchmark material, a type 321H stainless steel.

The optional shot-blasting operation on the inner tube surface increases significantly the steam oxidation resistance. The cold working caused by the shot-blasting promotes a fast diffusion of Cr towards the inside surface, increasing locally the Cr concentration and consequently the oxidation resistance.

Cold forming of TEMPALOY AA-1 tubes

Rules for heat treatment of cold bent TEMPALOY AA-1 tubes are given by ASME 2007 Section 1 PG-19. If the finishing-forming temperature is below 1160 °C (2120 °F) or if percentage strain calculated as:

\[
\text{% strain} = \frac{100r}{R}
\]

(where \( r \) is the nominal radius of the tube and \( R \) the bending radius) exceeds the values indicated in Table 6, a solubilization heat treatment is necessary.

The soaking time shall be 20 minutes per inch of thickness or 10 minutes, whichever is greater.

The minimum solubilization temperature shall be 1160 °C (2120 °F), while the maximum temperature shall be 1245 °C (2270 °F).

### Physical properties

The main physical properties have been measured and are reported in Table 5.

<table>
<thead>
<tr>
<th>T [°C]</th>
<th>( C_p ) [J/g*°C]</th>
<th>( k ) [W/(m*K)]</th>
<th>( \alpha \times 10^{-6}/K )</th>
</tr>
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<tbody>
<tr>
<td>25</td>
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<tr>
<td>800</td>
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<td>24,5332</td>
<td>19,8</td>
</tr>
</tbody>
</table>

Table 5 - Main physical properties of TEMPALOY AA-1 (Tenaris data)

* Measured between 20 °C and the reference temperature

### Table 6

<table>
<thead>
<tr>
<th>Temperature °C</th>
<th>Inner Scale Thickness µm</th>
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</thead>
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<tr>
<td>600</td>
<td>28</td>
</tr>
<tr>
<td>650</td>
<td>37</td>
</tr>
<tr>
<td>700</td>
<td>50</td>
</tr>
<tr>
<td>750</td>
<td>63</td>
</tr>
</tbody>
</table>

Fig. 3 - Steam oxidation of TEMPALOY AA-1 in standard and shot-blasted condition

### Table 6 – Rules for heat treatment of cold bent TEMPALOY AA-1 tubes, from ASME 2007 Section 1 PG-19.

<table>
<thead>
<tr>
<th>Temperature °F</th>
<th>100% Solubilization Heat Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>2120</td>
<td>1160</td>
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</table>

* For simple bends of tube and pipes whose outside diameter is less than 3.5 in. (89mm), this limit is 20%

Table 6 - Rules for heat treatment of cold bent TEMPALOY AA-1 tubes, from ASME 2007 Section 1 PG-19.
Welding

TEMPALOY AA-1 tubes can be welded without pre-heating and PWHT. Specific similar welding consumables for GTAW and SM AW processes have been developed by Kobelco and are currently available on the market as TG-S1AS and NC-B1AS respectively.

The use of approved fillers guarantees optimum welding results and enhanced creep resistance of the welded joints.

Creep tests on cross welded joints produced with Kobelco welding consumables show a creep resistance of the welded joint perfectly in line with that of base material (Fig. 5).